Results of 1993 Repeat-Pass SAR Interferometry Experiments

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1 Abstract:

In this talk we present results of a repeat-pass SAR interferometry experiment performed in June 1993 near Portage, Maine. Differential GPS data accurate to ±10cm were acquired to aid in motion compensation and geolocation of targets in the imagery. The experiment and data analysis will be discussed, and results will be shown during the presentation.

Keywords: SA R, interferometry, repeat-pass

2 Introduction:

It is well known that complex SAR imagery acquired simultaneously by two antennas separated by an appropriate baseline vector can be processed to yield an elevation map of the imaged scene. The JPL (l-hand TOPSAR sensor is one example or such a system [Z ebker et al, 1992]. It is one component Of the quadpolarization, three-frequency airborne SAR (AIRSAR) operated by JPL. The processing of TOPSAR data into terrain height maps is discussed in [Madsen et al, 1993].

Since low frequency radar penetrates foliage better than at high frequencies, one might hope that foliage height maps could be derived by differencing elevation maps estimated from low and high frequency SARs. Unfortunately, a lower frequency version of the C-band TOPSAR would require a baseline too large to allow both antennas to be easily accommodated aboard the NASA DC-8. In this paper another option is considered.

It is also possible to create terrain height maps without the use of dual antennas cm the SAR platform. Under appropriate conditions a height map mrry also be derived from two SAR images taken on different passes past the same target area. This is referred to as repeat-pass SAR interferornetry (RPI) [Gray/Farris-Manning, 1993]. in this technique, complex SAR imagery taken at two different times over the same area are Processed to derive terrain elevation information. Generally speaking this can be done if 1) the passes are close enough in time to avoid significant scene decorrelation, 2) the baseline vector between the two passes is '(sufficiently constant", 3) the baseline vector is not so long that the two images are spatially decorrelated and 4) not so short that signal phase differences will be too small to reliably estimate elevation. In addition, accurate location of the SAR platform at each pulse event is crucial to determine the interferometric baseline as a function of time as well as for accurate target location,

Hence if the repeat pass technique is implemented using the AIRSAR L- or P-band and SARS, this height map may be combined with the higher frequency map generated by TOPSAR to estimate tree heights over the imaged area. Of course the accuracy of the estimates depend strongly upon the depth ' of penetration of the low frequency SAR, so it is expected that P-band will be preferable to determine the ground level terrain map.

During 1993 two AJ{PA-sponsored experiments were performed with the JPL AIRSAR sensor to demonstrate the feasibility of the technique. The first was located near Portage, Maine in the northeastern US in a predominately coniferous forest. The second took place near Tully, Queensland in northeastern Australia in a tropical rainforest. Precise knowledge of the platform position vs. time was provirfed by a combination of the onboard INU measurements and differential GPS measurements using data acquired with JPL-designed Turborogue receivers. The G PS measurements are refined by post-processing of the raw Turborogue data at JPL.

in this talk we will present results of our attempt to
1) implement RPI using L- and P-band AIRSAR data and
2) to derive tree height maps for the Maine site using L- or P-band RPI in conjunction with C-band TOPSAR data ,
Note: the flight paths of the Australia experiment were less favorable for 1{1'1 than the Maine passes, but we hope to process this data at a later date.

3 The Experiment Site

The site used for the experiment is an area near the town of Portage in northern Maine, The terrain is gently rolling, varying in elevation from approximately 210 to 250 meters within the imaged area. It is covered with predominant ly coniferous forest, much of which is second-growth due to widespread logging in the area. There are many clearings in the area, mostly left over from logging activity. There are also some open fields used for hay, as the land is ill-suited to commercial farming. Many of these clear areas are suitable locations for corner reflector deployment.

This area has been used frequently in recent years by groups from MIT Lincoln Laboratory for radar foliage penetration experiments. As a result, a large amount of ground truth is available. This data includes measurements of biomass, tree height, etc. at selected sites over an area of approximately 20 Km^2. These'clata can be used to check estimate? of tree height derived using the technique mentioned above.

For this experiment, four 2.4m trihedral corner reflectors were placed in clearings within the imaged area, to be used as location references in the imagery. The reflectors enclosed an area extending approximately 4Km across- and along-track. Each of these was surveyed using Turborogue GPS receivers provided by the JPL Tracking Systems and Applications Section (TSAS). The survey was done in differential mode, using a reference GPS receiver 15Km from the site. Postprocessing of the reflector location data was done by TSAS to refine the position estimates [Lichten 1990]; see also [Webb/Zumberge, 1993]. The accuracy of these measurements is estimated to be better than ±10cm (relative to the reference receiver location). Most of this is due to uncertainty in the location of the phase centers of the reflectors relative to the survey points, since the uncertainty in the stationary GPS measurements alone is better than ±1cm.

4 Data Collection/GPS Processing

The JPL AIRSAR DC-8 flew eight passes over the site on June 24, 1993. An attempt was made to fly the same path on each pass, in the hope that at least one pair of passes suitable for RPI would be acquired. A Turborogue receiver on the DC-8 was used in conjunction with the reference Turborogue on the ground (located at the same reference point used to survey the marker reflectors) to obtain an accurate position history of each pass at one-second intervals. The SAR data was recorded in the TOPSAR mode at C-band and in the AIRSAR quadpolarization mode with 40MHz bandwidth at L- and P-band.

After the flight, the Turborogue data was processed by TSAS to obtain high-accuracy time series for the platform position. Accurate position estimation is obviously more difficult for the moving platform than for the stationary reflectors on the ground, but the accuracy was still very good. The worst-case position uncertainty for the GPS antenna on AIRSAR during flight was estimated to be better than ±10cm; the RMS error was less than 3cm. These ephemeris estimates are far better than any previously available for AIRSAR processing.

Each image required SAR data for a 20Km extent centered on the reflector array. To determine the best pairs of passes for interferometry, each pair was analysed as follows. One pass was arbitrarily chosen as a reference, and its 20Km flight path was fit to a line to determine an average velocity vector. The positions for the second pass were then projected onto this line, and these projected points were used as an approximate resampled version of the reference track; this was done to "line up" the GPS samples of the two tracks in time. The instantaneous baseline vectors for the pair were then approximated by the vectors between these pairs of points. This ensures that each baseline vector is perpendicular to the average flight path. The average and standard deviation of these instantaneous baselines was then computed. Using the results of this analysis, pairs were chosen for RPI processing for which 1) the length of the projection of their average baseline onto a plane perpendicular to the 45-degree look-angle vector was within the desired range of interferometric baseline lengths and 2) the standard deviation of the baseline variation was as small as possible.

5 SAR Data Processing

Once a pair of passes is selected, the next step is to put them in an appropriate reference frame for processing. Either of the passes may be used to derive this; it will be referred to as the reference pass. Once this is done, the GPS positions for both passes are transformed into the new reference frame.

A convenient frame is the "(s, c, h)" coordinate system, where s, c and h are respectively the along-track, cross-track and altitude variables of a "best fit" spherical approximation to the ellipsoid centered at the middle of the track. The (s, c, h) coordinate frame is not a Cartesian frame, but instead a spherical coordinate system designed to locally approximate the WGS84 reference ellipsoid. The approximate midpoint of the reference pass (as determined from the postprocessed GPS data) is used as the origin of the reference frame. The sphere is chosen to be locally tangent to the ellipsoid at the origin, and to have radius equal to the radius of curvature in the track direction. This surface will deviate from the WGS84 ellipsoid by less than 0.5111 for tracks up to 200Km long. In this system s denotes distance along the reference curve, which is a great circle in the approximating sphere. c is the distance measured along the arc perpendicular to the reference curve, h is the height above the reference ellipsoid.

Having transformed the GPS data into the (s, c, h) system, it must then be used to determine the antenna phase center at each transmit pulse time. The postprocessed GPS data, while very accurate, is not sampled fast enough (1Hz) to do this accurately. On the other hand, the AIRSAR LASERREF INU system is sampled much faster (50Hz) and is accurate over short time intervals, but has systematic errors which give rise to erroneous drifts in position estimates. This is especially true in the vertical direction, since these estimates are strongly dependent upon the exact local value of the gravitational constant g, which is unknown to the device.

This problem was addressed by combining the position estimates from the INU and the GPS sensors to retain the best features of the two in the final position estimates. Systematic errors in the INU were assumed to be essentially quadratic in nature. This is certainly true in the vertical direction, since this is precisely the effect of an error in g. The approach used will be outlined here and discussed below:

1) align the GPS and SAR data in time,
2) double-integrate the INU acceleration estimates to obtain INU position estimates,
3) compute the difference between the INU and GPS position estimates ($\Delta = P_{INU} - P_{GPS}$) for each GPS data point, interpolating the INU positions as appropriate,
4) do a quadratic fit of Δ in each dimension to the difference from step 3, and
5) subtract the quadratic fit in each dimension from the INU position data in that dimension.

This procedure is designed to remove the quadratic component of the drift between the INU positions and the accurate GPS positions from the INU data, but leaves the high-frequency INU information intact. Thus the GPS data are used as high-accuracy positions at a low sampling frequency, and the INU is used to "fill in the gaps" at the higher sampling rate.

Comments:

1) Each AIRSAR echo has an associated 128-byte header containing ancillary information such as transmit time, INU-measured accelerations, PRF, etc. The transmit time contained in this header is derived from a GOES satellite receiver on AIRSAR. This time is very accurate, hut only 1msec precision is available, making this time unsuitable for pulse-to-pulse timing computations. Thus the GOES time was only used to align the GPS data with the INU data after accounting for the propagation time from the GOES satellite. This offset is a function of the sensor location and is approximately constant for a given data set

2) The major causes for INU measurements drifting from true position estimates are unknown and uncompensated acceleration hisses in the INU. These are approximately constant over a data take. This is the reason quadratics were fit to the residuals above, In the vertical direction we also must compensate for the fact that the INU uses a value of g that is not altitude-compensated. This accounts for an additional acceleration bias in the vertical direction.

once precise locations arc available for the antenna phase centers at each transmit event, RPI processing can proceed as outlined in [Madsen et al, 1993], with some modifications. First, motion compensation is done to a common reference line as described in [Gray/Farris-Manning, 1993] instead of parallel reference lines as described in [Madsen et al, 1993]. Also, the TOPSAR/AIRSAR instrument transmits a variable PRF to maintain a constant along-track spacing between pulses, which is linked to the INU velocity. Since the INU velocity estimates are not sufficiently accurate, the true along-track spacing varies from pass to pass. This necessitates interpolating (presuming) the two data sets to the same constant along-track spacing, as well as to align the pulses. In addition, the raw complex imagery is cross-correlated and the resulting offsets are used to obtain fine residual motion estimates not compensated for with the aforementioned motion compensation scheme. **Minor** modifications to the scatterer location algorithm arc also required to account for the spherical geometry and the common reference line approach.

once RPI and TOPSAR processing is complete, the relative penetration at the two bands may be estimated by differencing the TOPSAR and RPI terrain maps. This will hopefully be strongly correlated to tree heights.

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